# Improving Surface Forcing of the Marginal Seas

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## LONG-TERM GOAL

The PI's long-term goal is to understand the physical processes of the air-sea interaction and coupling of the ocean and the atmosphere on the regional scale and to predict the variability of the coupled ocean-atmosphere system.

## OBJECTIVES

The main objectives of this study are (1) to better understand the variability of the surface forcing from diurnal-to-seasonal time scales in the Red Sea, the Gulf of Aden, and the Arabian Gulf-Strait of Hormuz regions and (2) to examine the influence of complex coastal terrain and the atmospheric aerosols on the surface winds, radiative and air-sea fluxes in the Arabian Marginal Seas and Gulfs (AMSG).

## APPROACH

The complex coastline and coastal topography in AMSG contribute to a large uncertainty in the global analysis of the surface forcing fields, which are not resolved by relatively low-resolution global models. As a result, these model analysis fields cannot capture the strong diurnal cycle in surface wind and temperature fields. Another challenging problem is the abundant aerosol in the region and its impact on the radiative fluxes is largely unknown. To explore these science issues, we use the Penn State University/National Center for Atmospheric Research atmospheric nonhydrostatic mesoscale model (MM5) to characterize the small scale and mesoscale structures of atmospheric forcing in AMSG. Our general approach is to use multi-nested grids model to cover a large area in the outer domain and still resolve the fine mesoscale features in the inner domains. We use a triple-nest with 45, 15, and 3 km grid spacing for the outer and two inner domains, respectively. The outer domain covers the entire AMSG (including the Red Sea) and the northern Indian Ocean. The NCEP global analysis fields are used to initialize MM5 and provide continuous lateral boundary conditions. The outer domain is run in a four-dimensional data assimilation (FDDA) mode to provide the best possible boundary conditions for the inner domains. The two inner nested domains are run in a forecast mode with no FDDA. The initial model simulations indicate that the NECP SST analysis field is generally too cold and lack of spatial structure near the coastal regions. It is inadequate to use as model lower boundary conditions in this kind of study. So we first have to generate a merged satellite SST data for the region using the AVHRR and TRMM/TMI measurements, similar to that of Chen et al. (2001). To further explore the potential impact of aerosols on the radiative fluxes, we will use the NOGAPS and

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Navy Aerosol Analysis and Prediction System output fields as initial and lateral boundary conditions for the regional models (MM5 and Navy COAMPS) in AMSG.

**WORK COMPLETED**

During the past year (FY2001-2002), we have completed two month-long MM5 simulations of February and August 2001, respectively, during which the ONR/NSF-supported REDSOX1 and REDSOX2 research cruises have been in AMSG taking observations. The model simulation has been evaluated/validated with both the satellite and in situ observations including the METEOSAT-7 cloud top temperature and water vapor images, the NASA QuikSCAT surface winds, and the surface measurements from the stations near the coastal regions. The model reproduces the strong diurnal cycle of the surface wind and temperature fields very well. We have generated a merged satellite SST data for the region using the AVHRR and TRMM/TMI measurements, similar to that of Chen et al. (2001). The satellite-based SST fields are proved to be crucial in reproducing the observed seasonal changes in surface heat fluxes. In addition to model simulations and data analyses, we have developed a real-time meteorological data archive and display system online at RSMAS/University of Miami for the AMSG region (http://orca.rsmas.miami.edu/amsg ). This web site has been used by the PIs to aid the ONR supported field program in AMSG (REDSOX1 and REDSOX2 in February and August 2001).

**RESULTS**

We first compare the model results with the available ship observations along the ship track (Fig. 1). The surface meteorological conditions are well simulated by the model. Fig. 2 shows an example of the MM5 simulated surface winds compared with the shipborne wind observations during the REDSOX1. The research cruise starts near the east coast of the central Africa where the northeasterly winter monsoon prevails (Fig. 2, 11-17 February). The surface winds are mostly easterlies in the Gulf of Aden, except in the strait of Bab el Mandeb when the ship experience the strong south-southeasterly wind that is a persistent feature enhanced by the high mountains on both sides of the strait. The model captures these features very well.

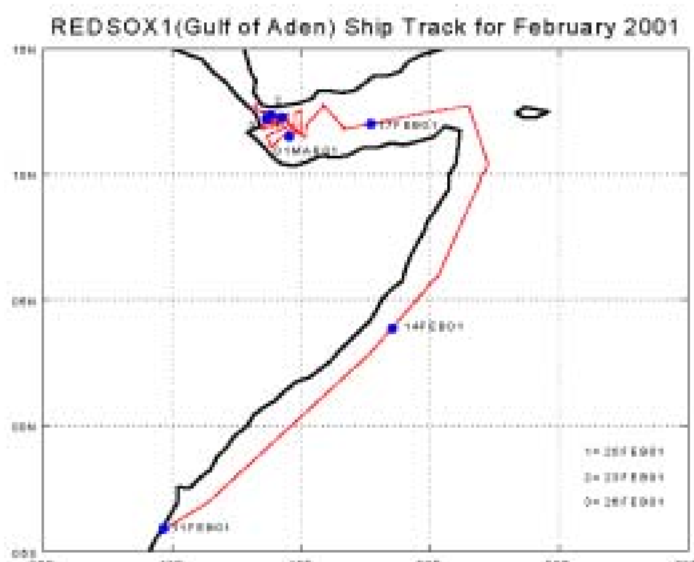


***Fig. 1 REDSOX1 ship track.***

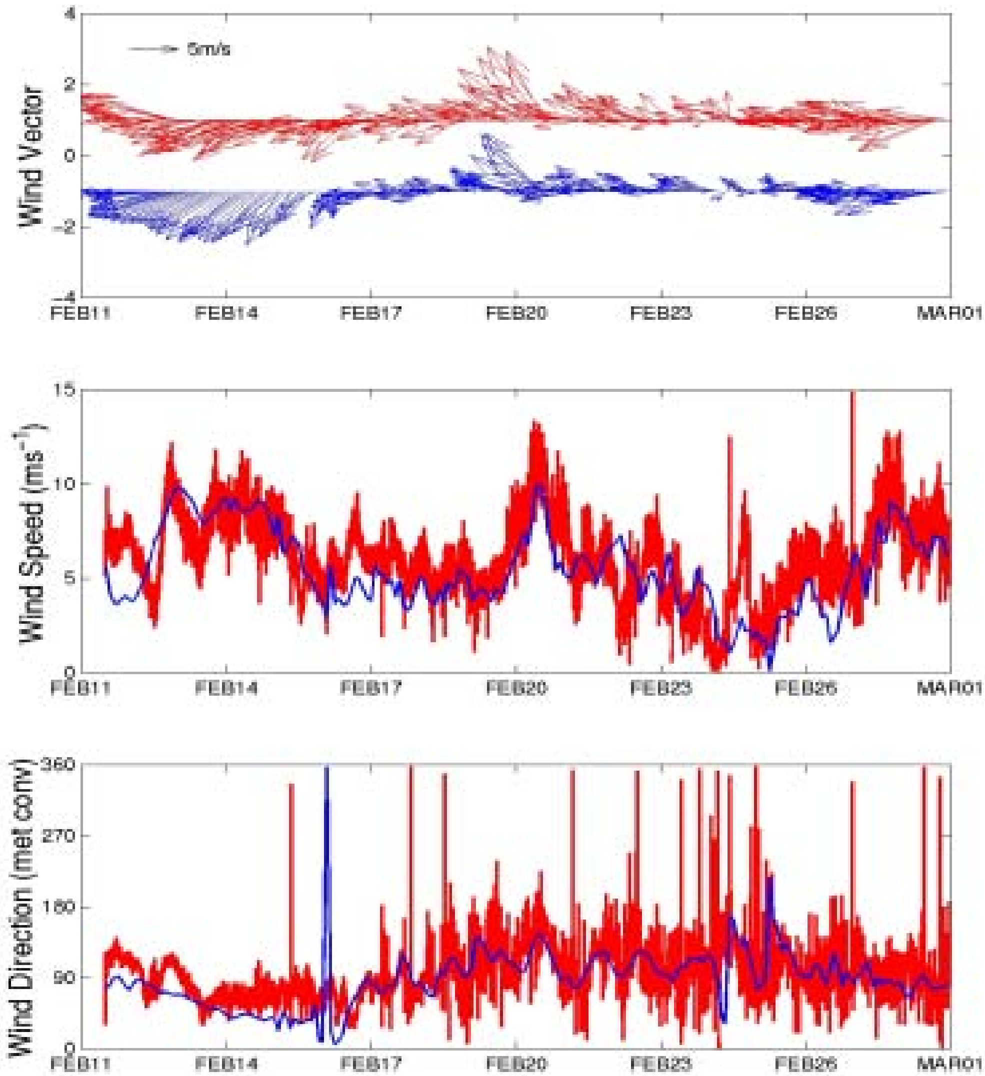


***Fig. 2 Comparison of MM5 simulated (blue) and observed (red) surface meteorology data from the REDSOX1 research cruise during February 2001.***

Fig. 3 shows the monthly mean net surface heat fluxes from the MM5 simulations and the NCEP analysis for February and August 2001. The strong contract between the seasonal winter and summer monsoon conditions is clearly shown in the region (comparing Fig. 3a and 3b). During the winter month (February), the ocean loses heat over most of the AMSG region with a maximum heat loss at the northern end of the Red Sea. This maximum heat loss in the northern end of the Red Sea is in part responsible for the deep water formation in the northern Red Sea. During the summer month (August), two local maxima of ocean heat loss are in the central-southern Red Sea and in the Gulf of Aden, respectively, where orographically induced strong local wind maxima are located.

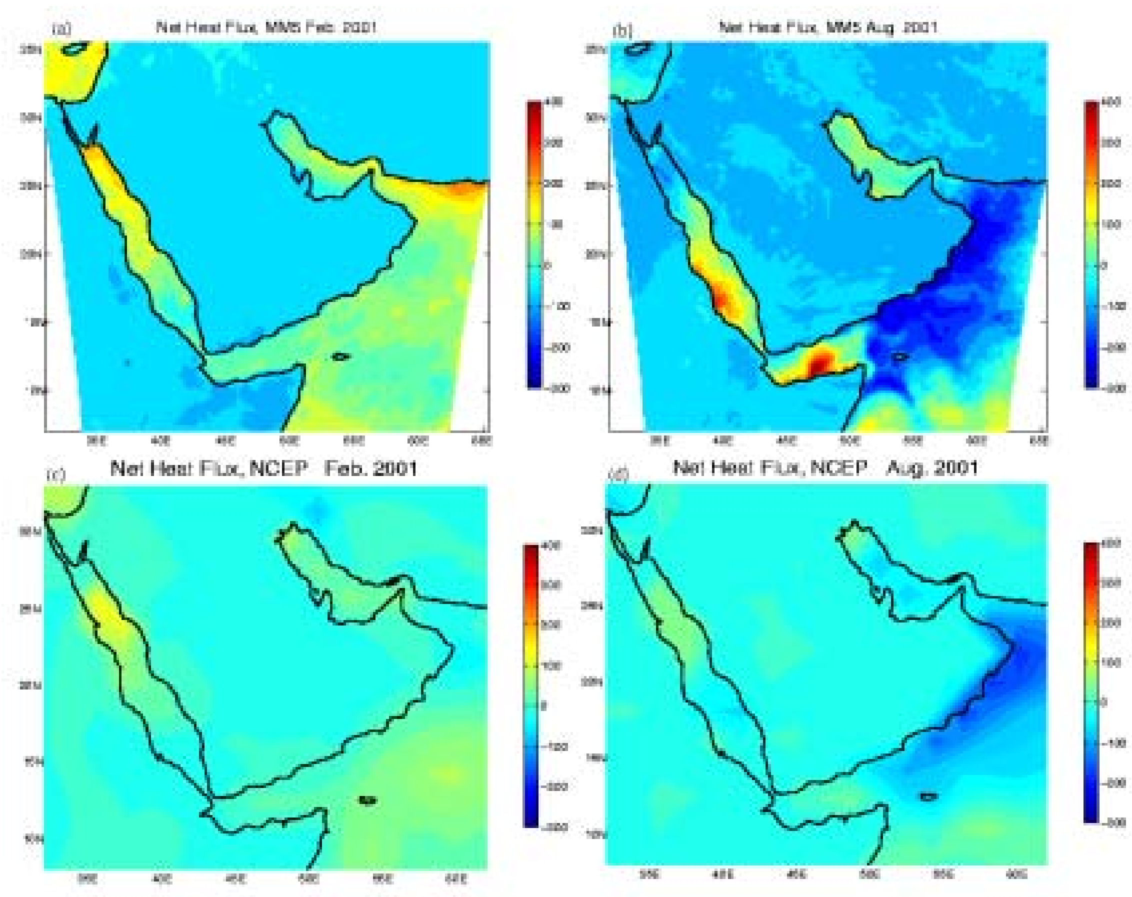


***Fig. 3 Net surface heat fluxes (color scale in W m$^{-2}$) from the MM5 simulations (a and b) and the NCEP analysis (c and d) for February and August 2001, respectively. The positive (negative) value indicates the net ocean heat loss (gain).***

Over the open ocean region of the Arabian Sea the net surface heat flux changes from a moderate heat loss in February to a relatively strong heat gain in August. MM5 produced net surface heat fluxes (Fig. 3a and 3b) are very similar to the observations of Weller et al. (1998) from the IMET buoy deployed in the Arabian Sea (61.5E, 15.5N) during October 1994-October 1995. In contrast, the net surface heat flux from the NCEP analysis has no coastal features (Fig. 3c and 3d), partly because of the lack of spatial resolution to resolve the coastal mountains. In the Red Sea, the maximum heat flux is missing in the northern end (cf. Fig. 3a and 3c) during the winter and lack of the seasonal changes in the summer (Fig. 3d). The maximum heat flux in the Gulf of Aden during the summer (Fig. 3b), well simulated by MM5, is related to the warm SST and an extremely strong nocturnal wind jet channeled through a valley in the high mountains in the northern Ethiopia. This feature is also absent in the NCEP analysis.

MM5 is able to simulate both the NE and SW monsoon flows in February and August and several distinct local wind systems in the region. In the Red Sea, there three jets influenced by the unique topographical features. The seasonal changes in the near surface wind and heat flux fields are dominated by the monsoon circulation in the AMSG region. They are also closely related to the local diurnal cycle. During the night, several nocturnal jets, both in the northern and central Red Sea and in the Gulf of Aden, are evident in August. These nocturnal jets located downstream of large valleys, which are enhanced by the down sloping wind due to the diurnal temperature changes in the mountains. The large nocturnal jet in the Gulf of Aden is confirmed by the QuikSCAT satellite observations. During the day, the on-shore flow is dominant in the Arabian Gulf, the Red Sea, and the coastal region of the Arabian Sea. In addition to the diurnal cycle, there is evidence that the atmospheric forcing fluctuates on the synoptic time scales as well.

## IMPACT/APPLICATIONS

This project has provided the first high spatial and temporal resolution surface forcing (heat and momentum fluxes) associate with the diurnal variability in AMSG. The model simulated surface forcing fields will be used compare with the observations from in situ measurements from various cruises in AMSG and to drive the ocean circulation and surface wave models.

Recent ocean circulation and wave model simulations using MM5 surface forcing in JES have show a great sensitivity in ocean response to the high-resolution atmospheric forcing which is very different from that climatological mean forcing and the ECMWF global (Mooers et al., 2001, Zhao et al., 2001).

## TRANSITIONS

The full three-dimensional, high-resolution atmospheric forcing fields (including all surface fluxes) will be made available to all ONR PIs for their data analysis of REDSOX1 and REDSOX2 in AMSG and to the ocean modeling groups at NRL Stennis and UM as well other ONR supported modeling efforts. The results on the sensitivity to different boundary layer and surface flux parameterizations will be tested in COAMPS as we conduct similar simulations using COAPMS in AMSG.

## RELATED PROJECTS

Related projects include the ONR DRI of the Japan/East Sea (S. Chen), the NASA/JPL QuikSCAT (S. Chen), ONR Arabian Marginal Seas and Gulfs (W. Johns, D. Olson).

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